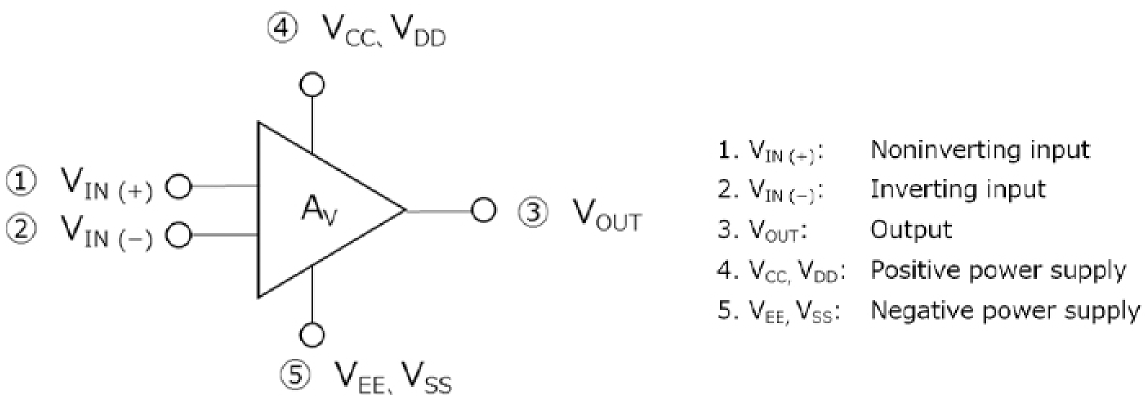
Operational Amplifier (Op-Amp)

The operational amplifier (Op-Amp) is one of the most important core concepts in analog electronic circuits and **is commonly used to amplify the weak signals from sensors.**

Types of Operational Amplifiers:

- Non-Inverting Amplifier
- Inverting Amplifier
- Differential Amplifier

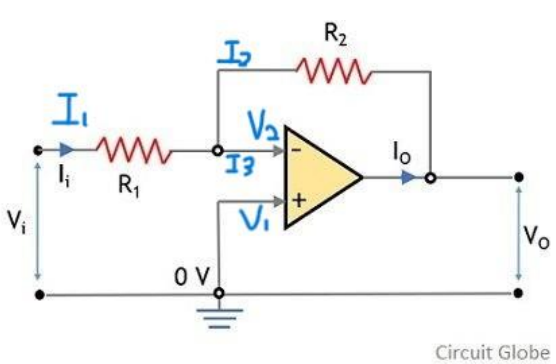


Inverting Amplifier

An inverting amplifier is an Op-Amp circuit where the input signal is connected to the negative input terminal (-) of the Op-Amp, and the positive input terminal (+) is grounded. **The characteristic feature of an inverting amplifier is that the output signal is the inverse of the input signal, meaning it is phase-shifted by 180 degrees.**

Vout = -R2 /R1*Vin, where R2 is the feedback resistor, R1 is the input resistor, Vin is the input voltage, Vout is the output voltage.

Circuit Structure:



The output voltage (Vout) is inversely proportional to the input voltage (Vin). This inverse relationship is a defining feature of inverting amplifiers.

Gain Formula:

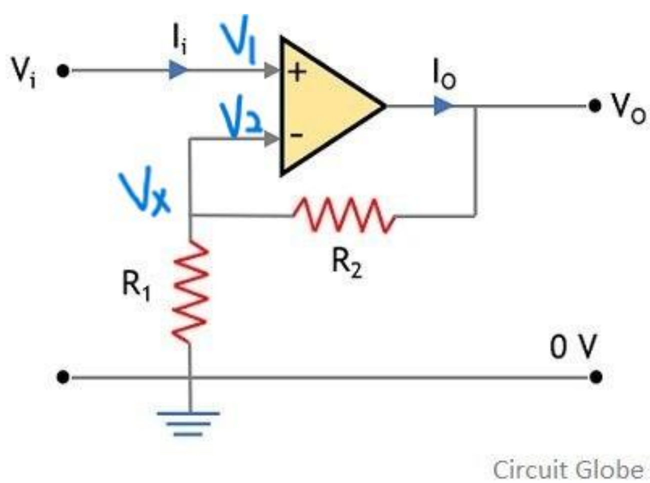
The gain ratio (Av) of an inverting amplifier is given by: **Av = -R2 / R1**. The gain is determined by the ratio of the resistors. Hence, to achieve a desired gain, one needs to adjust the values of Rf and Rin.

Non-Inverting Amplifier

A non-inverting amplifier is an Op-Amp circuit where the input signal is directly connected to the positive input terminal (+) of the Op-Amp, and the negative input terminal (-) is connected to the output through a feedback resistor. The output signal is in phase with the input signal, meaning there is no phase inversion.

Formula: **Vout = (1+R2/R1)*Vin**, where R2 is the feedback resistor, R1 is the ground resistor, Vin is the input voltage, Vout is the output voltage

The output voltage is directly proportional to the input voltage. Therefore, in a non-inverting amplifier, Vout and Vin are proportional.



Gain Formula:

The gain ratio (Av) of a non-inverting amplifier is given by: **Av = 1 + R2 / R1**, where Rf is the feedback resistor and Rin is the input resistor.

Comparison Table for Inverting and Non-Inverting Amplifiers

Comparison Item	Inverting Amplifier	Non-Inverting Amplifier
Input Signal	Input to the negative terminal (inverting input)	Input to the positive terminal (non-inverting input)
Output Signal	Out of phase with the input signal	In-phase with the input signal
Phase Relationship	Output signal is 180 degrees out of phase with the input signal	Output signal has the same phase as the input signal
Phase difference	180°	0°
Gain Ratio of Amplifier	-Rf / Rin	1+ Rf / Rin
Ground connection	Positive input terminal	Negative input terminal
Input Impedance	Determined by the input resistor Rin	High
Output Impedance	Low	Low

Differential Amplifier

A differential amplifier is a type of amplifier circuit that amplifies the difference between two input signals while suppressing any signals common to both inputs. This makes differential amplifiers widely used for noise suppression and signal processing.

Structure: A differential amplifier has two input terminals and one output terminal. It amplifies the voltage difference between the two input signals, effectively canceling out any common-mode signals.

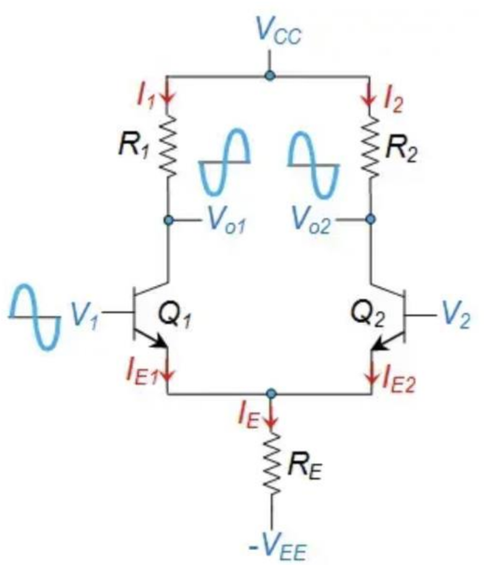


Figure 1 A BJT Differential Amplifier

Formula: Vout = Ad * (Vin_+ - Vin_-) + Ac * (Vin_+ + Vin_-)/2, where Ad is the differential gain Ac is the common-mode gain, Vin+ is the positive input voltage, Vin− is the negative input voltage

Gain Formula: **Av = Rf / Rin**, where Rf is the feedback resistor and Rin is the input resistor.

CMRR (Common Mode Rejection Ratio)

CMRR is an important parameter that measures the ability of an amplifier to suppress common-mode signals. It is defined as the ratio of differential gain (Ad) to common-mode gain (Ac).

Formula: **CMRR = Ad / Ac**. CMRR is usually expressed in decibels (dB) as: **CMRR (dB) = 20 log_10 * (Ad/Ac)**

Common Mode Signal

- A common-mode signal is the component of the input signals that is common to both inputs. **Differential amplifiers can effectively suppress common-mode signals, making them highly useful in noisy environments.**
- The ability of a differential amplifier to reject common-mode signals is judged by its CMRR value. **A higher CMRR indicates a better capability to eliminate common-mode signals.**